Planar Monopole With a Coupling Feed and an Inductive Shorting Strip for LTE/GSM/UMTS Operation in the Mobile Phone

Cheng-Tse Lee and Kin-Lu Wong

***Abstract*—A planar monopole having a small size yet providing two wide bands for covering the eight-band LTE/GSM/UMTS operation in the mobile phone is presented. The small-size yet wideband operation is achieved by exciting the antenna's wide radiating plate using a coupling feed and short-circuiting it to the system ground plane of the mobile phone through a long meandered strip as an inductive shorting strip. The coupling feed leads to a wide operating band to cover the frequency range of 1710–2690 MHz for the GSM1800/1900/UMTS/LTE2300/2500 operation. The inductive shorting strip results in the generation of a wide operating band to cover the frequency range of 698–960 MHz for the LTE700/GSM850/900 operation. The planar monopole can be directly printed on the no-ground portion of the system circuit board of the mobile phone and is promising to be integrated with a practical loudspeaker. The antenna's radiating plate can also be folded into a thin structure (3 mm only) to occupy a small volume of $3 \times 6 \times 40$ mm^3 (0.72 cm^3) for the eight-band LTE/GSM/UMTS operation; in this case, including the 8-mm feed gap, the antenna shows a low profile of 14 mm to the ground plane of the mobile phone. The proposed antenna, including its planar and folded structures, are suitable for slim mobile phone applications.**

***Index Terms*—Coupling feed, handset antennas, inductive shorting strip, mobile antennas, planar monopole.**

I. Introduction

Planar monopoles with a wide radiating plate are simple in configuration and have been shown to generate wideband operation to cover the multiband WWAN (wireless wide area network) communications [1], [2] for mobile phone applications. However, in order to cover the GSM operation in the 900-MHz band, the wide radiating plate in the planar monopole usually occupies a large volume and is required to be in the folded structure to achieve a reduced size for internal mobile phone antenna applications. In the reported designs, this kind of planar monopole for covering the 900-MHz band operation requires the use of a folded radiating plate of size $10 \times 10 \times 70$ mm^3 (7.0 cm^3) [1] or $10 \times 15 \times 35$ mm^3 (5.25 cm^3) [2]. In addition to the large volume occupied, the thickness of the folded radiating plate is as large as 10 mm, which is not promising for applications in the modern slim mobile phone which generally requires its internal antenna to have a thin profile of 4 mm or less [3]–[8]. When a planar radiating plate is used, it is reported that a planar monopole with a size of 30×50 mm^2 (1500 mm^2) can have a wide operating band of 870–2450 MHz for the mobile phone [9]. However, the large size of 1500 mm^2 will greatly limit its applications in the internal mobile phone antennas.

In this communication, we present a novel planar monopole design having a small size yet capable of generating two wide operating bands to cover the eight-band LTE/GSM/UMTS operation in the mobile phone, which includes the LTE700 (698–787 MHz), GSM850 (824–894 MHz), GSM900 (880–960 MHz), GSM1800 (1710–1880 MHz), GSM1900 (1850–1990 MHz), UMTS (1920–2170 MHz), LTE2300 (2305–2400 MHz) and LTE2500 (2500–2690 MHz) bands. Notice that the LTE (long term evolution) operation [10] can provide better mobile broadband and multimedia services than the existing GSM and UMTS mobile networks [11] and is expected to become attractive for the mobile users. The lower band of the proposed planar monopole can have a large bandwidth to cover the frequency range of 698–960 MHz for the LTE700/GSM850/900 operation. The upper band can have an even larger bandwidth (>1 GHz) to cover the frequency range of 1710–2690 MHz for the GSM1800/1900/UMTS/LTE2300/2500 operation. The proposed planar monopole is suitable to be directly printed on the no-ground portion of the system circuit board of the mobile phone, making it easy to fabricate at low cost. The size of the wide radiating plate of the planar monopole is 12×40 mm^2 or 480 mm^2 only, which is much smaller than those in [1], [2] (both at least 1400 mm^2). When including the 8-mm feed gap, the no-ground portion required in the proposed design is 20×40 mm^2 (800 mm^2), which is much less than that (1500 mm^2) in [9]. The antenna can also be integrated with a nearby loudspeaker in a compact configuration. To achieve small size yet wideband operation, the proposed planar monopole is excited using a coupling feed and short-circuited to the system ground plane of the mobile phone through a long meandered strip as an inductive shorting strip. Detailed effects of the coupling feed and the inductive shorting strip are discussed in the communication.

Further, the radiating plate of the proposed antenna can be folded into a thin structure (3 mm only) to occupy a small volume of $3 \times 6 \times 40$ mm^3 (0.72 cm^3 only) for the eight-band LTE/GSM/UMTS operation. The 3 mm in thickness is promising for applications in the modern slim mobile phone. In this case, by including the 8-mm feed gap between the radiating plate and the system ground plane of the mobile phone, the antenna also shows a low profile of 14 mm to the top edge of the ground plane. Details of the proposed antenna are presented.

II. Proposed Antenna

Fig. 1(a) shows the geometry of the proposed planar monopole with a coupling feed and an inductive shorting strip for the eight-band LTE/GSM/UMTS operation in the mobile phone. Dimensions of the metal pattern of the antenna are given in Fig. 1(b). A 0.8-mm thick FR4 substrate is used as the system circuit board of the mobile phone. The 1-mm thick plastic casing (relative permittivity 3.0 and conductivity 0.02 S/m) enclosing the circuit board as the casing of a slim mobile phone has a thin profile of 9.8 mm. On the circuit board there is a printed system ground plane of size 40×100 mm^2 and a no-ground portion of size 40×20 mm^2.

The planar monopole is printed on the no-ground portion and comprises a wide radiating plate of size 12×40 mm^2 flushed to the top edge of the circuit board. Between the radiating plate and the ground plane, there is a feed gap of length 8 mm. A simple coupling strip of length (t) 12.5 mm, which is connected to the 50-Ω microstrip feedline printed on the circuit board through a 8-mm long metal strip across the feed gap, capacitively excites the radiating plate. Across the feed gap, there is also a long meandered metal strip to short circuit the radiating plate to the ground plane. The meandered metal strip has a length of about 31 mm and a narrow width of 0.3 mm and behaves like a simple shorting strip loaded with a chip inductor (see Ref3 in the inset of Fig. 11; detailed discussion will be given in Section IV). The meandered metal strip is hence considered as an inductive shorting strip here.

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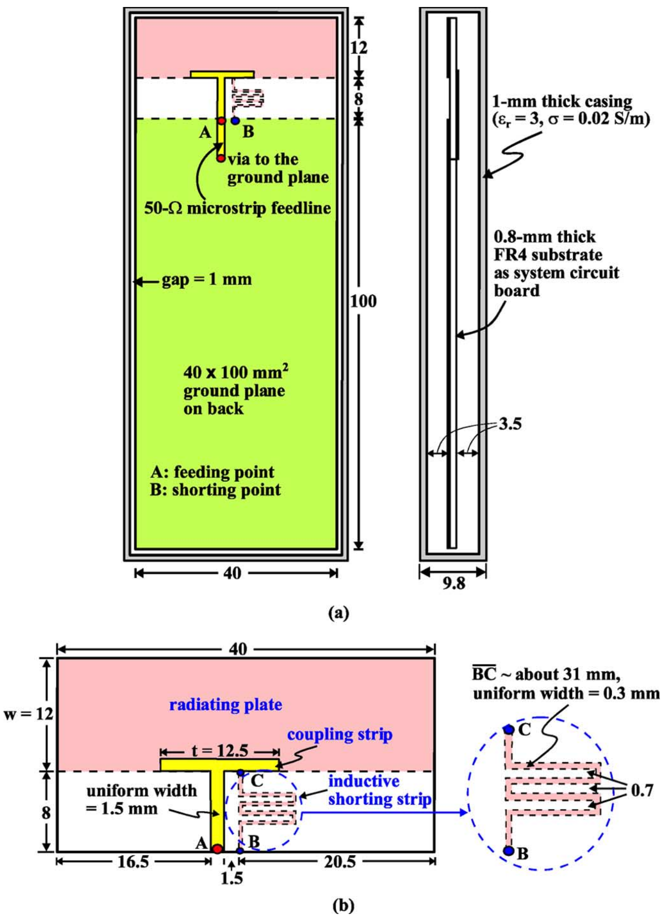


Fig. 1. (a) Geometry of the proposed planar monopole with a coupling feed and an inductive shorting strip for the eight-band LTE/GSM/UMTS operation in the mobile phone. (b) Dimensions of the metal pattern of the antenna.

The coupling feed applied in this study effectively compensates for the large inductive reactance over a wide frequency range, especially over the desired upper band of 1710–2690 MHz. This leads to a very wide operating band obtained for the antenna's upper band to cover the GSM1800/1900/UMTS/LTE2300/LTE2500 operation. This coupling-feed effect is different from that applied for the internal WWAN antennas for mobile phone or laptop computer applications [12]–[18], in which the coupling feed mainly leads to enhanced bandwidth for the antenna's lower band at about 900 MHz [12]–[16] or causes the excitation of the one-eighth-wavelength resonant mode as the antenna's lowest mode for the 900-MHz band operation [17], [18]. The different coupling-feed effect obtained here is related to the use of the wide radiating plate in the proposed design, which is different from the long, narrow radiating strips used in [12]–[16]. The coupling-feed effect in the proposed design is also different from the use of a long (26 mm) coupling T-strip protruded from the ground plane, which is mainly for decreasing the lowest resonant frequency of the antenna [9].

By incorporating the use of the inductive shorting strip, a wide operating band to cover the frequency range of 698–960 MHz for the LTE700/GSM850/900 operation can be generated. Detailed effects of the inductive shorting strip on the generation of the antenna's wide lower band are discussed with the aid of Fig. 3 in Section III. Also note that without the use of the wide radiating plate, that is, when the width w of the radiating plate is decreased (the preferred width w is 12 mm in this design), good impedance matching over the desired wide frequency range of 698–960 MHz cannot be achieved (see the results shown in Fig. 5; detailed discussion will be given in Section III). Although there

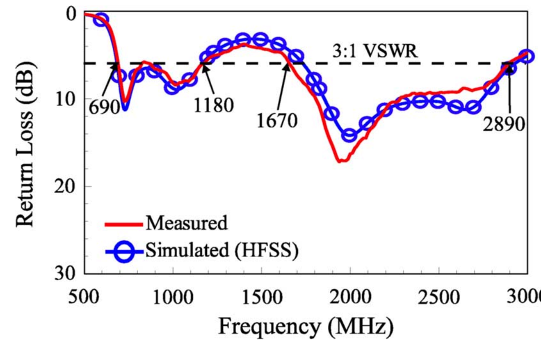


Fig. 2. Measured and simulated return loss of the proposed antenna.

are large effects of the inductive shorting strip on the antenna's lower band, the impedance matching for frequencies over the desired upper band of 1710–2690 MHz is relatively slightly affected. This makes it easy to fine-tune the desired lower and upper bands for the antenna to cover the eight-band LTE/GSM/UMTS operation.

The proposed antenna can also be in other possible embodiments for practical applications. The first one is to use a chip-inductor-loaded shorting strip replacing the inductive shorting strip and is shown in Ref3 in the inset of Fig. 11. The second one is to have its wide radiating plate folded into a thin structure (3 mm in thickness) such that the folded radiating plate occupies a small volume of $3 \times 6 \times 40\ \mathrm{mm}^3$ or $0.72\ \mathrm{cm}^3$ only (see Ref4 in the inset of Fig. 12). The third one is to integrate with a nearby loudspeaker [19]–[21] such that a compact integration of the proposed antenna in the mobile phone is achieved. For these possible embodiments, the eight-band LTE/GSM/UMTS operation can also be obtained. Detailed results will be discussed in Section IV.

III. Results and Discussion

Fig. 2 shows the measured and simulated return loss of the proposed antenna. The measured data agree with the simulated results obtained using Ansoft simulation software HFSS version 11.2 [22]. With the 3:1 VSWR bandwidth definition, which is widely used as the design specification of the internal mobile phone antenna for WWAN communications [3]–[5], [9], two wide operating bands are obtained. The lower band shows a wide bandwidth of 490 MHz (690–1180 MHz), while the upper band has an even wider bandwidth of 1220 MHz (1670–2890 MHz). The wide lower and upper bands cover the LTE700/ GSM850/900 and GSM1800/1900/UMTS/LTE2300/2500 operation, respectively.

Fig. 3 shows the comparison of the simulated return loss for the proposed antenna, the case with a direct feed and a simple shorting strip (Ref1) and the case with a coupling feed and a simple shorting strip (Ref2). The corresponding dimensions for the three studied antennas in the figure are the same. Ref2 applies a coupling feed to replace the conventional direct feed used in Ref1. From the results of Ref1 and Ref2, a much wider bandwidth for Ref2 than for Ref1 is seen. The obtained bandwidth for Ref2 reaches about 1.7 GHz, from about 1.1 to 2.8 GHz; while the bandwidth for Ref1 is less than 300 MHz.

From the comparison of Ref2 and proposed antenna in Fig. 3, a wide lower band centered at about 900 MHz is generated, which is owing to the use of the inductive shorting strip replacing the simple shorting strip in Ref2. There are two resonant modes, the first one at about 700 and the second one at about 1000 MHz, contributed to the obtained wide lower band. The first one is owing to the presence of the inductive shorting strip, while the second one is related to the resonant mode at about 1.5 GHz for Ref2. This is mainly because the inductive shorting strip causes the lengthening of the effective resonant path of the antenna, which not only generates a new additional resonant mode but also shifts

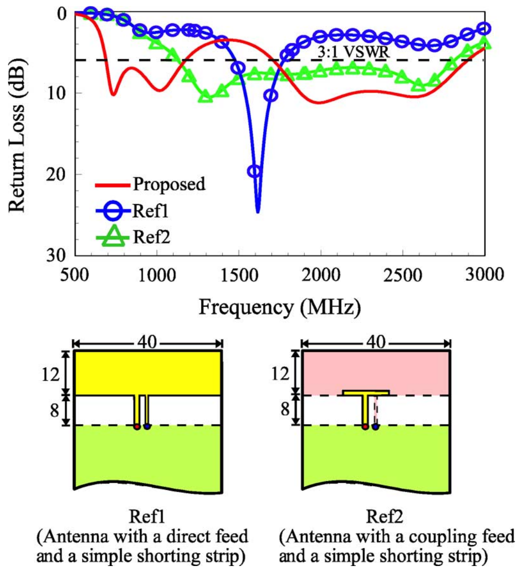


Fig. 3. Simulated return loss for the proposed antenna, the corresponding antenna with a direct feed and a simple shorting strip (Ref1) and the corresponding antenna with a coupling feed and a simple shorting strip (Ref2).

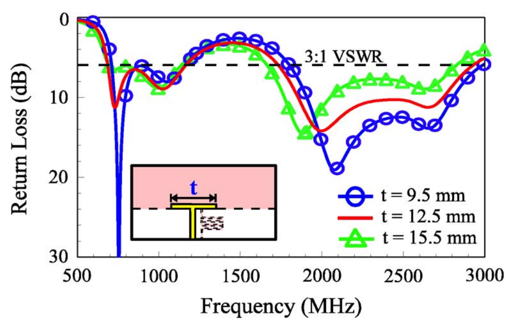


Fig. 4. Simulated return loss as a function of the length t of the coupling strip. Other dimensions are the same as in Fig. 1.

the 1.5 GHz resonant mode of Ref2 to lower frequencies. It is also seen that the input impedance for higher frequencies larger than about 1.7 GHz is very slightly varied for Ref2 and proposed antenna. A wide upper band covering the desired frequency range of 1710–2690 MHz is thus maintained.

Effects of varying the length t of the coupling strip are also studied. The simulated return loss for the length t varied from 9.5 to 15.5 mm is shown in Fig. 4. Small effects on the antenna's lower band are seen. The bandwidth of the upper band, however, can be controlled by the length t. By increasing the length t, the upper band is shifted to lower frequencies. That is, by selecting a proper length t (12.5 mm in this study), the upper band can be adjusted to cover the desired frequency range of 1710–2690 MHz.

The simulated return loss for the width w of the radiating plate varied from 2 to 12 mm is presented in Fig. 5. Large effects of the width w on the antenna's lower band are seen. When the width w decreases, the obtained bandwidth of the antenna's lower band is quickly decreased and becomes unable to cover the desired frequency range of 698–960 MHz. Some effects on the upper band are also seen, which are, however, small compared to those on the lower band.

The simulated surface current distributions at typical frequencies are shown in Fig. 6. At 750 and 1000 MHz, relatively strong excited surface current distributions are seen in the system ground plane, compared to those at higher frequencies. An additional current null is also seen at

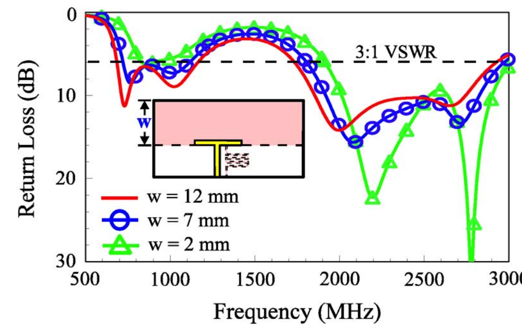


Fig. 5. Simulated return loss as a function of the width w of the radiating plate. Other dimensions are the same as in Fig. 1.

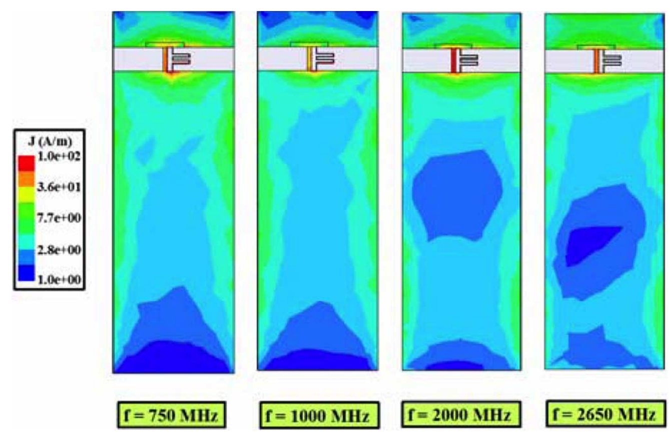


Fig. 6. Simulated surface current distributions at 750, 1000, 2000, and 2650 MHz.

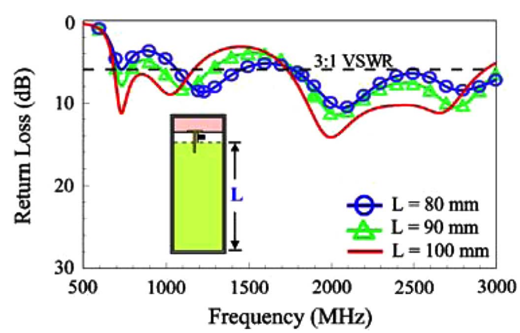


Fig. 7. Simulated return loss as a function of the length of the system ground plane. Other dimensions are the same as in Fig. 1.

about the center of the system ground plane; this is owing to the shorter wavelength at higher frequencies. On the other hand, relatively strong surface current distributions in the radiating plate are seen at 2000 and 2650 MHz than at lower frequencies. These results indicate that the system ground plane is an important radiating part, especially at lower frequencies.

Effects of the length of the system ground plane on the antenna performances are studied in Fig. 7. Results of the simulated return loss for the length L varied from 80 to 100 mm are shown. Large effects on the obtained 3:1 VSWR bandwidth for the lower band are seen. When the length L is decreased, the impedance matching for frequencies between the two resonant modes in the lower band is degraded. For the upper band, however, the effects are relatively small and the obtained bandwidth is generally about the same.

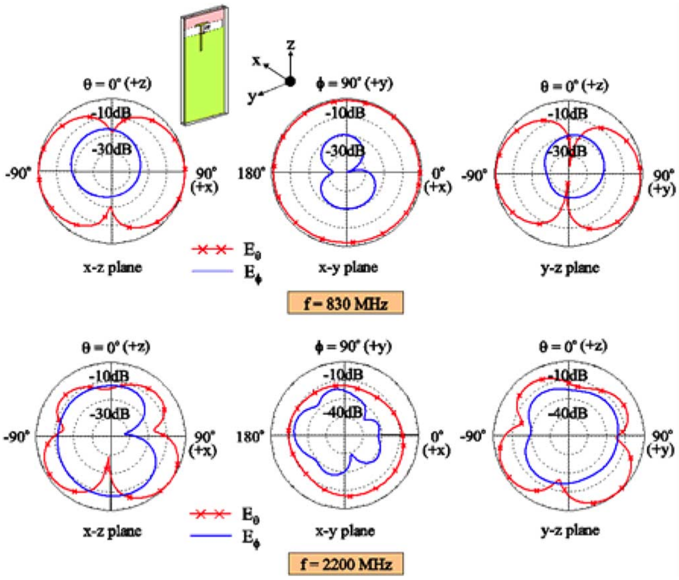
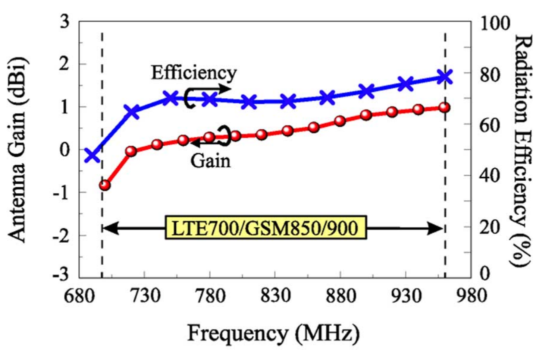
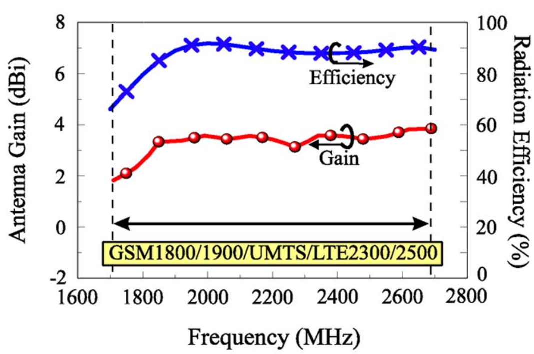


Fig. 8. Measured radiation patterns at 830 and 2200 MHz for the proposed antenna.



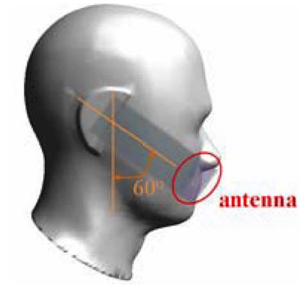
(a)



(b)

Fig. 9. Measured antenna gain and simulated radiation efficiency of the proposed antenna. (a) The lower band. (b) The upper band.

Fig. 8 plots the measured radiation patterns at 830 and 2200 MHz (about central frequencies of the desired lower and upper bands). At 830 MHz, dipole-like radiation patterns with omnidirectional radiation in the azimuthal plane (x-y plane) are observed. While at 2200 MHz, more variations in the patterns are seen. Also note that measured radiation patterns at other frequencies in the lower and upper bands showed similar results as those plotted in Fig. 8. The obtained radiation patterns also show no special distinctions to those of the printed internal WWAN mobile phone antennas [16]–[18]. Fig. 9



Frequency (MHz)	740	860	925	1795	1920	2045	2350	2595
Return Loss (dB)	16.9	9.9	11.8	13.1	18.3	12.6	11.1	9.6
1-g SAR (W/kg)	1.31	1.50	1.58	1.19	0.84	0.98	0.94	0.69
10-g SAR (W/kg)	0.96	1.07	1.16	0.72	0.51	0.58	0.51	0.35

Fig. 10. SAR simulation model and the simulated SAR values for 1-g and 10-g head tissues for the proposed antenna placed at the bottom of the mobile phone. The return loss indicates the impedance matching level at the testing frequency.

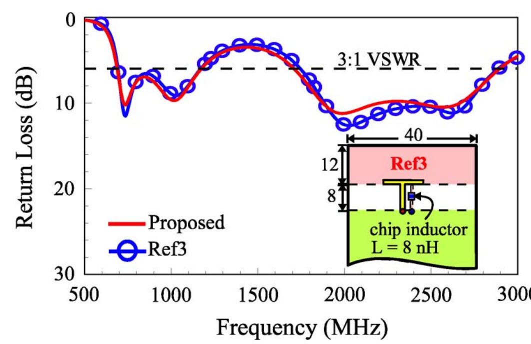


Fig. 11. Comparison of the simulated return loss for the proposed antenna and the corresponding antenna with a coupling feed and a chip-inductor-loaded shorting strip (Ref3).

shows the measured antenna gain and simulated radiation efficiency. Over the 698–960 MHz band shown in Fig. 9(a), the antenna gain is about -0.8–0.9 dBi radiation and the radiation efficiency ranges from about 52% to 78%. Over the 1710–2690 MHz band in Fig. 9(b), the antenna gain is about 1.9–3.8 dBi, and the radiation efficiency ranges from about 68% to 92%.

The SAR (specific absorption rate) values of the proposed antenna are also tested using the simulation software SEMCAD [23]. Since it is known that this kind of printed antenna with no ground plane on back is suitable to be placed at the bottom of the mobile phone to obtain decreased SAR values [24], [25], only the proposed antenna at the bottom of the mobile phone as shown in the simulation model in Fig. 10 is tested. The obtained SAR values are given in the figure, which are all below the SAR limit of 1.6 W/kg for the 1.0-g head tissue and 2.0 W/kg for the 10-g head tissue [26]. The results suggest that the proposed antenna is promising for practical mobile phone applications.

IV. Other Embodiments of the Proposed Antenna

The inductive shorting strip in the proposed antenna can be replaced by a simple shorting strip loaded with a chip inductor. Fig. 11 shows the comparison of the simulated return loss for the proposed antenna and the corresponding antenna with a coupling feed and a chip-inductor-loaded shorting strip (Ref3). The chip inductor has an inductance of 8 nH (selected from the aid of Ansoft HFSS simulation) and is not necessarily to be placed in the middle of the shorting

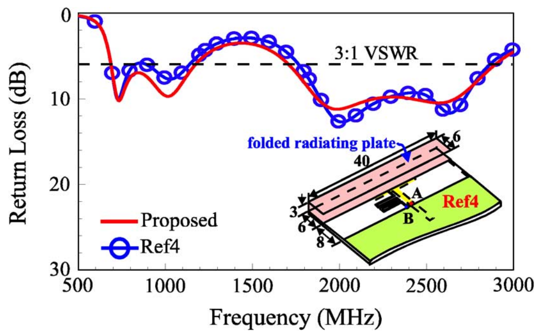


Fig. 12. Comparison of the simulated return loss for the proposed antenna and the case with a folded radiating plate (Ref4). Both cases have the same ground-plane dimensions.

strip. There are almost no differences in the simulated return loss for the proposed antenna and Ref3. This also confirms that the long meandered shorting metal strip can be treated as an inductive shorting strip.

The antenna structure of Ref4 in the inset of Fig. 12 shows that the wide radiating plate of the proposed antenna can be in the folded structure with a thin thickness of 3 mm and a small volume of $3 \times 6 \times 40$ mm^3 (0.72 cm^3). Notice that the total length of the folded radiating plate of Ref4 is 15 mm, longer than that (12 mm) of the printed structure shown in Fig. 1. In this case, as shown in Fig. 12, the obtained return loss of Ref4 is about the same as that of the proposed antenna. Ref4 also shows a low profile of 14 mm to the system ground plane of the mobile phone, which is smaller compared to that (20 mm) of the proposed antenna in Fig. 1.

The proposed antenna can also be in compact integration with a practical loudspeaker [19]–[21]. The measured return loss for the cases with and without the loudspeaker is about the same (measured data not shown for brevity), indicating that such a compact integration is promising for practical applications. Also note that, by using the loudspeaker simulation model in [21], [27], the simulated results indicate that the radiation efficiency will be decreased by about 5% in the lower band and about 10% in the upper band, which may be owing to some lossy materials contained in the loudspeaker.

V. Conclusion

A planar monopole with a wide radiating plate excited by a coupling feed and short-circuited by an inductive metal strip has been shown to achieve small size yet wideband operation for applications in the mobile phone to cover the eight-band LTE/GSM/UMTS operation. The proposed antenna can be in an all-printing structure or folded thin structure; both structures can provide two wide operating bands to cover the desired frequency ranges of 698–960 and 1710–2690 MHz. The antenna can also be in compact integration with a practical loudspeaker. The obtained results indicate that the proposed antenna is suitable to be applied in the modern slim mobile phone for the eight-band LTE/GSM/UMTS operation.

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